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# A REPORT ON THE VALUES OF GRAVITY IN THE MALDIVE AND LACCADIVE ISLANDS

BY

E. A. GLENNIE, Lt.-Col., R.E., D.S.O.,

*Geodetic Branch, Survey of India.*

WITH ONE PLATE AND FOUR CHARTS

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# A REPORT
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1. Foreword.—For four weeks in March and April, 1934, No. 14 Party, Survey of India, collaborated with the John Murray Expedition, making gravity observations at eight places in the Maldive Islands, and at one station, Minikoi (Minicoy), in the Laccadive Islands.

The following account is largely a reprint from the Survey of India Geodetic Report, 1934, Chapter III, with the addition of appendices giving descriptions of the gravity stations, a summary of the Hayford reductions and details of density determinations from the cores of the Funafuti boring.

Gravity results in the Maldive Islands should be considered in relation to those obtained on the west coast of India, which are discussed more fully in Geodetic Report 1934.

2. Gravity Results.—These are shown in Tables I and II and in Pl. I, fig. 2. Their relation with India is shown in Charts I to IV. Descriptions of stations are given in Appendix I.

3. Hayford Reductions.—In addition to the depths given in the latest Admiralty Charts and in the Prince of Monaco's ocean maps, those obtained by the continuous echo-sounding apparatus on H.E.M.S. "Mabahiss" have been used. The Expedition made special runs in order to obtain the profile of the bank on the east and west sides of the archipelago. These are shown in Pl. I, fig. 1. A smooth curve giving the average profile was drawn from these and employed where other depth data were not available. The sites of the gravity stations were always on the lagoon side of the island, so topographical changes in the nearer zones were small. In view of the very considerable amount of depth data available the Hayford reduction work may be considered free from appreciable error.

The depth estimations and Hayford reductions for Dr. Vening Meinesz's submarine

gravity station near Minikoi have been entirely redone; the final Hayford correction amounted to + 0·0266 g. as compared with + 0·0260 g. obtained by the United States Coast and Geodetic Survey—a close agreement which may be considered very satisfactory.

The Hayford reduction zones and tables given in Survey of India Professional Paper XV have been employed throughout for this work.

4. Discussion of Results.—The large negative anomalies in the Maldives are remarkable; these increase towards the central meridian of the Archipelago. Precisely the opposite is the case at Minikoi, for the crustal warp anomaly is positive on land and reduces to zero at the sea station to the west, thus indicating a tectonic condition under the Laccadives apparently opposite to that under the Maldives.

From the gravity and deflection observations on the west coast of India it is known that a positive area flanks the coast as far south as Mangalore; if this is extended to Minikoi it is significant that a line drawn from Minikoi to Mangalore will skirt the southern margin of Kalpeni and Androth Islands, Ellicalpeni Bank and other shallow soundings. It seems therefore a plausible deduction that the great positive upwarp off the Bombay coast runs south under the Laccadives to Minikoi, while the flanking depression of the crust on its east side continues out to sea south of Mangalore to the line of the Maldives, where a continental fragment of the crust has been crushed in the downwarp or submerged.

This conclusion is supported by V. Meinesz's work in the Java Sea. Sumatra and Java are flanked on the south and west by a great band of negative anomalies. This band persists whether its line is marked by islands or by deep sea. Over Sumatra and Java large positive gravity anomalies are found, but further east the high positive area underlies the deep Banda Sea, while the negative band continues along the curve of the islands to Coram.

Evidently the superficial conditions are incidental only; it is to the deeper warpings of the crust that the greater part of the anomalies must be referred.

The Admiralty Charts also show a marked difference between the Laccadive Islands and the Maldive Islands. Instead of the striking linear arrangement of the Maldives, with great atolls ten to twenty miles across, the Laccadives show a confused medley of small islands, reefs and banks.

Though the Laccadive Islands are believed to overlie an upwarped area of the crust, a small amount of recent submergence is not excluded. The original upwarp, if associated with the Aravalli upheaval, may have occurred in geologically remote times, but any subsequent contrary movement has been much less than the original upwarp.

5. The Formation of the Maldive Islands.—The formation of the Maldive Islands will be considered first with reference to the isostatic anomalies and secondly in the light of the crustal warp hypothesis.

(a) *Isostatic anomalies.*—In Fadiffolu Atoll the two stations Difuri and Kānifuri are at the extreme east and west margins of the atoll and there are no stations in the middle of the lagoon. In South Mālosmadulu Atoll, Fonimagudu is on the eastern edge and Turādu on the western edge, while Māmādu and Mandu are in the lagoon. All the anomalies are negative, and the largest anomalies are at the two stations in the lagoon.

In the Hayford corrections no allowance has been made for the low density of the

coral rock, since its thickness is unknown, and it is at the stations in the lagoon that the error on this account would be greatest.

Considering only the four stations in South Mālosmadulu Atoll, assume 3000 ft. thickness of coral rock, density 1·8, the deficiency in mass due to this low density being uncompensated. Changing the topographical corrections accordingly, the following result is obtained :

| | $g - \gamma_C$ (uncorrected). | $g - \gamma_C$ (corrected for coral 3000 ft. thick). |
|---|---|---|
| Fonimagudu . . . | — 73 mgal. | — 47 mgal. |
| Māmādu . . . | — 81 ,, | — 49 ,, |
| Mandu . . . . | — 77 ,, | — 45 ,, |
| Turādu . . . . | — 74 ,, | — 45 ,, |

The correction has therefore largely removed the discrepancy between the lagoon stations and the marginal stations.*

The same assumptions applied to the Difuri and Kānifuri correction give the following results :

| | $g - \gamma_C$ (uncorrected). | $g - \gamma_C$ (corrected). |
|---|---|---|
| Difuri . . . . | — 66 | — 36 |
| Kānifuri . . . . | — 71 | — 44 |

Kānifuri therefore falls into line fairly well, but Difuri is exceptional.

Considering the five accordant stations, the mean " corrected " anomaly is — 46 mgals., and assuming that this anomaly is due to an additional thickness of coral, density 1·8, again with the defect uncompensated, 4000 ft. additional thickness of coral is required. According to the usual explanation of the formation of coral islands over a subsiding land mass, however, isostatic adjustment is given as the cause of subsidence. Defect of mass is, therefore, inadmissible, so compensation must be allowed for. With compensation of the light coral rock an additional 5000 ft. thickness is required.

The isostatic anomalies therefore if solely due to the light coral rock imply a thickness of 7000 ft. of coral *uncompensated* or 12,000 ft. *compensated* ; 12,000 ft. thickness brings the coral deeper than the immediately surrounding ocean, a result which is only consistent with isostatic adjustment if the original land mass or bank on which the coral was formed was an upwarp of the ocean floor and not a continental relic of normal sial.

The density (1·8) which has been assumed for the coral is probably the lowest permissible ; computation with higher densities would yield greater thicknesses of coral.

These calculations are based on the Helmert gravity formula of 1901 ; if the Bowie formula or the International gravity formula of 1930 were used, the computations would require very much greater thicknesses of coral. The formula based on the Survey of India spheroid which is used for the $g - \gamma_F$ anomalies would give better results, since it reduces the Helmert negative anomalies over the Maldives by 18 mgals. The total

* A coral thickness of 3000 ft. gives the best result, since the discrepancy is larger if a thickness of 2500 ft. or 3500 ft. is assumed.

resulting thickness of coral (density 1·8) is then about 5000 ft. uncompensated or 9000 ft. compensated.

The employment of this same gravity formula in India without additional corrections would be unsatisfactory. The negative anomaly in South India would indeed be reduced, but this apparent advantage would be offset by a greatly increased area of very high positive anomalies in the northern part of the Peninsula. The use of this formula for the adjacent Maldive region without additional corrections is, therefore, hardly justified.

The conclusion, therefore, from this investigation of the isostatic anomalies is that, if the isostatic anomalies are due to local, superficial anomalies of density, the Maldive Islands mark the original site of an oceanic ridge, *not a continental block*, which has since sunk down under isostatic adjustment. Under Minikoi is part of the same ridge not yet isostatically adjusted.

(b) *Crustal warping.*—According to the hypothesis of crustal warping, gravity anomalies are mainly due to the up and down warpings of the lower layers of the crust. These tend to balance out, and over a very wide area equilibrium is reached very closely. This is a necessary result of the working of the ordinary laws of mechanics and of strength of materials.* Hence the Hayford method of computation provides an easy means of allowing for this general equilibrium. When computing the $g - \gamma_F$, or crustal warp, anomaly, Hayford compensation is assumed to be lacking over an area of about 1600 square miles immediately surrounding the station. This anomaly is then assumed to give a measure of the underlying crustal warping, combined with the effect due to local departures of the superficial strata from normal density. In India there appears to be a general broad warping of the lower crustal layers superimposed on the more local warpings. In order to give prominence to the local warpings and so to bring out more clearly the local tectonic structure, a " hidden range " correction is applied to the crustal warp anomalies, which is intended to remove the effects of the general warping. In the Maldive Islands there is no reason to assume any general warping of this nature, nor is it likely. The crustal warp anomalies, therefore, contain no " hidden range " correction.

If the underlying rock has a smooth level surface, which is not improbable, the argument used for the extra large isostatic anomalies at the two lagoon stations holds good also for the $g - \gamma_F$ anomalies. In the table below are given (1) the isostatic anomaly, $g - \gamma_{CS}$, using the gravity formula on which the crustal warp anomalies are based, (2) the crustal warp anomaly $g - \gamma_F$, and (3) $g - \gamma_F$ corrected for the effect of 3000 ft. of coral, density 1·8.

| | $g - \gamma_{CS}$. | $g - \gamma_F$. | $g - \gamma_F$ (corrected for 3000 ft. of coral). |
|---|---|---|---|
| Difuri | — 48 mgals. | — 28 mgals. | + 2 mgals. |
| Kānifuri | — 53 ,, | — 43 ,, | — 15 ,, |
| Fonimagudu | — 55 ,, | — 48 ,, | — 23 ,, |
| Māmādu | — 63 ,, | — 58 ,, | — 26 ,, |
| Mandu | — 59 ,, | — 53 ,, | — 21 ,, |
| Turādu | — 56 ,, | — 39 ,, | — 10 ,, |

* See " The Hypothesis of Isostasy ", Dr. J. de Graaff Hunter, ' Monthly Notices of R.A.S., Geoph. Suppt.', January, 1932.

Interpreted according to the previous explanation, the $g - \gamma_F$ anomalies indicate a downwarp.* It can be assumed that the coral has formed over the top of a block of sial of normal density which has foundered in this downwarp. The small outer anomalies show the effect of flanking upwarps. The greatest anomaly may be taken as indicating the amount of downwarp. Table III in Professional Paper No. 27 gives a means of computing the approximate depth of the downwarp.

The following assumptions may be made :

(1) No thickness of coral—an unreal assumption, since there is no rock to be seen on the islands other than coral and the purely superficial beach or island sandstone.

(2) Three thousand feet of coral.

(3) Downwarping equal to the thickness of coral—an interesting assumption, which implies that coral formation has kept pace with subsidence if the original land was nearly at sea level.

Of course subsidence may not be quite the same as the downwarping ; there might be a sagging of the block in the middle, or, on the other hand, a crushing upwards of the block.

The table below gives results according to the above three assumptions :

*Computed Depth of Downwarping.*

| Assumed thickness of coral. (Feet.) | Density 1·8. (Feet.) | Density 2·2. (Feet.) |
|---|---|---|
| *Nil* | 17,000 | 17,000 |
| 3000 | 7500 | † |
| 4200 | 4200 | † |
| 6500 | † | 6500 |

Referring to the seaward profile shown in Pl. I, fig. 1, there appears to be a definite change of slope about 3 sea miles out. If the steeper inner slope is the talus slope of coral debris outside the atoll, then the outer, more gentle slope may be assumed to be an uncovered portion of the underlying sial block. Continuing this slope inwards, it rises to a depth of about 700 fathoms below the atoll, so that a capping of about 4000 ft. of coral is required.

Plainly the crustal warp anomalies alone cannot yield a definite result for the thickness of the coral, but the conclusion drawn from them is that the Maldive Islands overlie an area where a block of sial has subsided as a result of the downwarping of the lower crustal layers. Whether this conclusion or that derived from the isostatic anomalies is to be preferred is a matter for argument in the light of the various theories of coral island formation, continental drift and so on.

* The crustal warp hypothesis assumes the warping of an intermediate layer underlying the light outer granitic layer. If the upper layer alone has been downfolded, then a much greater amount of downfolding is required to explain the negative anomalies.

† Not computed.

TABLE I.—*Gravity Observations.*

| No. | Station. | Date. | Height. | Latitude. | Longitude. | g. | p.e. |
|---|---|---|---|---|---|---|---|
| | | | ft. | ° ′ ″ | ° ′ ″ | gal. | mgal. |
| 333 | Midu . . . | 22.iii.34 | 5 | S0 35 54 | E73 10 45 | 978·105 | ±0·9 |
| 334 | Timārifuri . . | 24.iii.34 | 4 | N2 13 12 | E73 09 18 | 978·129 | 2·1 |
| 335 | Difuri . . . | 29.iii.34 | 4 | N5 23 36 | E73 38 00 | 978·122 | 1·4 |
| 336 | Kānifuri . . | 31.iii.34 | 4 | N5 22 12 | E73 19 12 | 978·107 | 1·2 |
| 337 | Fonimagudu . | 2.iv.34 | 4 | N5 15 54 | E73 10 24 | 978·109 | 1·2 |
| 338 | Māmādu . . | 4.iv.34 | 4 | N5 13 30 | E73 03 36 | 978·095 | 1·2 |
| 339 | Mandu . . | 5.iv.34 | 4 | N5 11 30 | E72 58 00 | 978·102 | 1·0 |
| 340 | Turādu . . | 7.iv.34 | 5 | N5 02 42 | E72 48 42 | 978·109 | 1·0 |
| 341 | Minikoi . . | 10.iv.34 | 6 | N8 19 03 | E73 03 51 | 978·221 | 1·0 |
| | Dr. V. Meinesz's sea station | 22.xi.23 | 0 | N8 06 | E72 48 | 978·116 | .. |

TABLE II.—*Gravity Anomalies, in milligals.*

| No. | Helmert's formula of 1901. | | | International formula of 1930. | Survey of India formula. | |
|---|---|---|---|---|---|---|
| | $g-\gamma_A$. | $g-\gamma_B$. | $g-\gamma_{CH}$. | $g-\gamma_{CI}$. | $g-\gamma_{CS}$. | $g-\gamma_F$. |
| 333 | + 74 | + 85 | − 87 | − 106 | − 70 | − 46 |
| 334 | + 92 | + 65 | − 76 | − 95 | − 59 | − 41 |
| 335 | + 46 | + 57 | − 66 | − 85 | − 48 | − 28 |
| 336 | + 32 | + 38 | − 71 | − 90 | − 53 | − 43 |
| 337 | + 35 | + 33 | − 73 | − 92 | − 55 | − 48 |
| 338 | + 22 | + 24 | − 81 | − 100 | − 63 | − 58 |
| 339 | + 30 | + 31 | − 77 | − 96 | − 59 | − 53 |
| 340 | + 40 | + 48 | − 74 | − 93 | − 56 | − 39 |
| 341 | + 84 | + 115 | − 30 | − 49 | − 12 | + 19 |
| V. M.'s station | − 25 | + 101 | − 52 | − 71 | − 34 | ± 0 |

Helmert's formula of 1901 $\gamma_O = 978{\cdot}030\ (1 + 0{\cdot}005\ 302 \sin^2\phi - 0{\cdot}000\ 007 \sin^2 2\phi)$ gal.
International formula of 1930 $\gamma_O = 978{\cdot}049\ (1 + 0{\cdot}005\ 288 \sin^2\phi - 0{\cdot}000\ 006 \sin^2 2\phi)$.
Survey of India formula $\gamma_O = 978{\cdot}013\ (1 + 0{\cdot}005\ 234 \sin^2\phi - 0{\cdot}000\ 006 \sin^2 2\phi)$.

$g-\gamma_A$ = Free air anomaly; $g-\gamma_B$ = Bouguer anomaly; $g-\gamma_C$ = isostatic anomaly; $g-\gamma_F$ = crustal warp anomaly.

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## LIST OF CHARTS.

CHART I.—Gravity anomalies (Hayford); contours showing $g-\gamma_{CH}$.

CHART II.—Gravity anomalies; contours showing $g-\gamma_F$.

CHART III.—Gravity anomalies; contours showing $g-\gamma_{CI}$.

CHART IV.—Crustal structure lines.

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# APPENDIX I

## DESCRIPTION OF GRAVITY STATIONS.

At all stations, except Mandu, the pendulum apparatus was set up in two small tents placed end-to-end. These consisted of a light 2-fly tent, 8 ft. by 8 ft. in size, and a single fly *shouldāri* 10 ft. by 8 ft. in size. In most of the islands the vegetation is very dense, and no space could have been found to pitch a large tent without a great deal of clearing. The height was obtained by clinometer from the lagoon water-level at half tide.

### STATION No. 333.

MALDIVE ISLANDS.

*Midu* (*North-east Side of Addu Atoll*).

The gravity station is sited 35 yds. from the lagoon shore and about $\frac{1}{4}$ mile south-west of Midu village, from which it is separated by a tidal creek.

An Admiralty Bench-mark is 27 yds. south of the station—good water obtainable.

### STATION No. 334.

MALDIVE ISLANDS.

*Timārifuri* (*South of Kolumadulu Atoll*).

The gravity station is sited close to the lagoon shore on the west side of a small uninhabited island north of Timārifuri.

### STATION No. 335.

MALDIVE ISLANDS.

*Difuri* (*East of Fadiffolu Atoll*).

The gravity station is sited close to the lagoon shore on the west side of the uninhabited island of Difuri, about one mile from the south end of the island. Good water is obtainable from a *pakka* well.

### STATION No. 336.

MALDIVE ISLANDS.

*Kānifuri* (*West of Fadiffolu Atoll*).

The gravity station is sited close to the lagoon shore on the north side of the uninhabited island of Kānifuri.

## STATION No. 337.

MALDIVE ISLANDS.

*Fonimagudu (East of South Mālosmadulu Atoll).*

The gravity station is sited close to the lagoon shore on the west side of the small uninhabited island of Fonimagudu. This island is about 5 miles south-east of Kumādu and 10 miles north-east of Duravandu. Good water is obtainable from two *kacha* wells.

## STATION No. 338.

MALDIVE ISLANDS.

*Māmādu (in lagoon of South Mālosmadulu Atoll).*

The gravity station is sited close to the shore on the south side of the island, which is uninhabited. The island is locally called Modu.

## STATION No. 339.

MALDIVE ISLANDS.

*Mandu (in lagoon of South Mālosmadulu Atoll).*

The gravity station is sited close to the shore on the south side of the island, which is uninhabited.

The pendulum apparatus was installed in a small thatched shelter, about 12 ft. by 10 ft. in size, found in the island.

## STATION No. 340.

MALDIVE ISLANDS.

*Turādu (West of South Mālosmadulu Atoll).*

The gravity station is sited in a clearing just south of the village.

## STATION No. 341.

LACCADIVE ISLANDS.

*Minikoi.*

The gravity station is sited close to the lagoon shore, about 250 yds. from the north end of the island.

# APPENDIX II

## MEAN CORRECTIONS TO $\gamma_0$ FOR TOPOGRAPHY AND ISOSTATIC COMPENSATION FOR SEPARATE ZONES.

| Zone. | Average height (ft.). | Topog. (mgals.). | Comp. (mgals.). | Topog. and comp. | Average height (ft.). | Topog. (mgals.). | Comp. (mgals.). | Topog. and comp. |
|---|---|---|---|---|---|---|---|---|
| | Station No. 333. | | | | Station No. 334. | | | |
| A | + 5 | + 0·10 | 0 | + 0·10 | + 4 | + 0·08 | 0 | + 0·08 |
| B | + 2 | + 0·04 | 0 | + 0·04 | + 2 | + 0·02 | 0 | + 0·02 |
| C | — 3 | 0 | 0 | 0 | — 1 | 0 | 0 | 0 |
| D | — 4 | — 0·01 | 0 | — 0·01 | — 7 | — 0·01 | 0 | — 0·01 |
| E | — 6 | — 0·01 | 0 | — 0·01 | — 14 | — 0·01 | 0 | — 0·01 |
| F | — 10 | 0 | 0 | 0 | — 180 | — 0·16 | + 0·03 | — 0·13 |
| G | — 66 | — 0·01 | + 0·01 | 0 | — 454 | — 0·28 | + 0·07 | — 0·21 |
| H | — 133 | — 0·01 | + 0·02 | + 0·01 | — 716 | — 0·38 | + 0·10 | — 0·28 |
| I | — 216 | — 0·02 | + 0·06 | + 0·04 | — 999 | — 0·74 | + 0·28 | — 0·46 |
| J | — 640 | — 0·13 | + 0·36 | + 0·23 | — 1,633 | — 1·48 | + 0·91 | — 0·51 |
| K | — 2,462 | — 1·22 | + 1·99 | + 0·77 | — 2,423 | — 1·82 | + 1·96 | + 0·14 |
| L | — 4,139 | — 1·72 | + 4·23 | + 2·51 | — 3,239 | — 1·64 | + 3·30 | + 1·66 |
| M | — 6,346 | — 2·78 | + 11·81 | + 9·03 | — 3,998 | — 1·75 | + 7·41 | + 5·66 |
| N | — 7,096 | — 2·13 | + 16·70 | + 14·57 | — 4,661 | — 1·30 | + 10·91 | + 9·61 |
| O | — 8,940 | — 3·06 | + 34·59 | + 31·53 | — 6,903 | — 2·16 | + 26·59 | + 24·43 |
| P | —10,060 | — 2·74 | + 33·38 | + 30·64 | — 7,506 | — 1·80 | + 24·74 | + 22·94 |
| 18 | —10,070 | .. | .. | + 6·21 | — 8,850 | .. | .. | + 5·45 |
| 17 | —10,440 | .. | .. | + 6·45 | — 9,370 | .. | .. | + 5·79 |
| 16 | —10,910 | .. | .. | + 6·77 | —10,040 | .. | .. | + 6·22 |
| 15 | —11,600 | .. | .. | + 7·24 | —10,810 | .. | .. | + 6·73 |
| 14 | —12,150 | .. | .. | + 7·62 | —11,400 | .. | .. | + 7·16 |
| 13 | —12,240 | .. | .. | + 12·02 | —11,970 | .. | .. | + 11·75 |
| 12 | —11,590 | .. | .. | + 7·11 | —11,870 | .. | .. | + 7·28 |
| 10, 11 | .. | .. | .. | + 9·90 | .. | .. | .. | + 9·30 |
| 7 to 9 | .. | .. | .. | + 6·10 | .. | .. | .. | + 5·85 |
| 1 to 6 | .. | .. | .. | + 1·38 | .. | .. | .. | + 1·40 |
| Total . . . . . | | | | + 160·25 | . . . . . | | | + 129·80 |
| | Station No. 335. | | | | Station no. 336. | | | |
| A | + 4 | + 0·08 | 0 | + 0·08 | + 4 | + 0·08 | 0 | + 0·08 |
| B | 0 | 0 | 0 | 0 | + 3 | + 0·03 | 0 | + 0·03 |
| C | — 1 | — 0·01 | 0 | — 0·01 | — 3 | — 0·01 | 0 | — 0·01 |
| D | — 1 | — 0·01 | 0 | — 0·01 | — 3 | — 0·01 | 0 | — 0·01 |
| E | — 12 | — 0·01 | 0 | — 0·01 | — 17 | — 0·01 | 0 | — 0·01 |
| F | — 35 | — 0·01 | 0 | — 0·01 | — 315 | — 0·45 | + 0·04 | — 0·41 |
| G | — 173 | — 0·06 | + 0·03 | — 0·03 | — 549 | — 0·41 | + 0·08 | — 0·33 |
| H | — 340 | — 0·10 | + 0·05 | 0·05 | — 1,202 | — 0·62 | + 0·17 | — 0·45 |
| I | — 790 | — 0·45 | + 0·22 | — 0·23 | — 1,885 | — 0·82 | + 0·40 | — 0·42 |
| J | — 1,835 | — 1·67 | + 1·02 | — 0·65 | — 1,606 | — 0·89 | + 0·90 | + 0·01 |
| K | — 3,182 | — 2·42 | + 2·57 | + 0·15 | — 1,685 | — 0·55 | + 1·36 | + 0·81 |
| L | — 3,812 | — 1·81 | + 3·90 | + 2·09 | — 1,783 | — 0·33 | + 1·82 | + 1·49 |
| M | — 4,537 | — 1·88 | + 8·41 | + 6·53 | — 1,619 | — 0·27 | + 2·98 | + 2·71 |
| N | — 5,192 | — 1·33 | + 12·16 | + 10·83 | — 2,670 | — 0·51 | + 6·22 | + 5·71 |
| O | — 4,547 | — 1·23 | + 17·41 | + 16·18 | — 4,228 | — 1·00 | + 16·17 | + 15·17 |
| P | — 6,210 | — 1·39 | + 21·09 | + 19·70 | — 6,350 | — 1·46 | + 20·88 | + 19·42 |
| 18 | — 6,870 | .. | .. | + 4·23 | — 7,330 | .. | .. | + 4·52 |
| 17 | — 7,400 | .. | .. | + 4·56 | — 7,990 | .. | .. | + 4·92 |
| 16 | — 8,200 | .. | .. | + 5·07 | — 8,840 | .. | .. | + 5·47 |
| 15 | — 9,040 | .. | .. | + 5·62 | — 9,450 | .. | .. | + 5·88 |
| 14 | — 9,660 | .. | .. | + 6·05 | — 9,970 | .. | .. | + 6·25 |
| 13 | —10,500 | .. | .. | + 10·29 | —10,600 | .. | .. | + 10·40 |
| 12 | —10,170 | .. | .. | + 6·22 | —10,340 | .. | .. | + 6·32 |
| 10, 11 | .. | .. | .. | + 8·73 | .. | .. | .. | + 8·73 |
| 7 to 9 | .. | .. | .. | + 5·37 | .. | .. | .. | + 5·38 |
| 1 to 6 | .. | .. | .. | + 1·42 | .. | .. | .. | + 1·42 |
| Total . . . . . | | | | + 113·45 | . . . . . | | | + 103·09 |

| Zone. | Average height (ft.). | Topog. (mgals.). | Comp. (mgals.). | Topog. and comp. | Average height (ft.). | Topog. (mgals.). | Comp. (mgals.). | Topog. and comp. |
|---|---|---|---|---|---|---|---|---|
| | Station No. 337. | | | | Station No. 338. | | | |
| A | + 4 | + 0·08 | 0 | + 0·08 | + 4 | + 0·08 | 0 | + 0·08 |
| B | 0 | + 0·01 | 0 | + 0·01 | 0 | 0 | 0 | 0 |
| C | — 2 | — 0·01 | 0 | — 0·01 | — 8 | — 0·01 | 0 | — 0·01 |
| D | — 4 | — 0·01 | 0 | — 0·01 | — 16 | — 0·01 | 0 | — 0·01 |
| E | — 38 | — 0·02 | 0 | — 0·02 | — 130 | — 0·07 | + 0·01 | — 0·06 |
| F | — 229 | — 0·26 | + 0·03 | — 0·23 | — 135 | — 0·04 | + 0·02 | — 0·02 |
| G | — 461 | — 0·27 | + 0·07 | — 0·20 | — 124 | — 0·02 | + 0·01 | — 0·01 |
| H | — 597 | — 0·20 | + 0·08 | — 0·12 | — 112 | — 0·01 | + 0·02 | + 0·01 |
| I | — 799 | — 0·31 | + 0·22 | — 0·09 | — 118 | — 0·01 | + 0·03 | + 0·02 |
| J | — 1,109 | — 0·45 | + 0·66 | + 0·17 | — 121 | — 0·01 | + 0·07 | + 0·06 |
| K | — 1,276 | — 0·32 | + 1·03 | + 0·71 | — 238 | — 0·01 | + 0·19 | + 0·18 |
| L | — 1,471 | — 0·23 | + 1·50 | + 1·27 | — 741 | — 0·04 | + 0·76 | + 0·72 |
| M | — 1,340 | — 0·18 | + 2·47 | + 2·29 | — 1,158 | — 0·14 | + 2·13 | + 1·99 |
| N | — 1,559 | — 0·18 | + 3·62 | + 3·44 | — 2,350 | — 0·40 | + 5·47 | + 5·07 |
| O | — 4,219 | — 1·01 | + 16·14 | + 15·13 | — 4,188 | — 1·06 | + 16·02 | + 14·96 |
| P | — 6,384 | — 1·45 | + 20·49 | + 19·54 | — 6,425 | — 1·49 | + 21·13 | + 19·64 |
| 18 | — 7,483 | .. | .. | + 4·61 | — 7,660 | .. | .. | + 4·72 |
| 17 | — 8,042 | .. | .. | + 4·96 | — 8,184 | .. | .. | + 5·05 |
| 16 | — 8,708 | .. | .. | + 5·38 | — 8,798 | .. | .. | + 5·44 |
| 15 | — 9,479 | .. | .. | + 5·90 | — 9,575 | .. | .. | + 5·96 |
| 14 | —10,008 | .. | .. | + 6·27 | —10,145 | .. | .. | + 6·35 |
| 13 | —10,746 | .. | .. | + 10·55 | —10,802 | .. | .. | + 10·61 |
| 12 | —10,343 | .. | .. | + 6·35 | —10,447 | .. | .. | + 6·41 |
| 10, 11 | .. | .. | .. | + 8·73 | .. | .. | .. | + 8·73 |
| 7 to 9 | .. | .. | .. | + 5·39 | .. | .. | .. | + 5·39 |
| 1 to 6 | .. | .. | .. | + 1·41 | .. | .. | .. | + 1·41 |
| Total . . . . . | | | | + 101·51 | . . . . . | | | + 102·69 |
| | Station No. 339. | | | | Station No. 340. | | | |
| A | + 4 | + 0·08 | 0 | + 0·08 | + 5 | + 0·10 | 0 | + 0·10 |
| B | 0 | 0 | 0 | 0 | + 3 | + 0·04 | 0 | + 0·04 |
| C | — 3 | — 0·01 | 0 | — 0·01 | — 1 | 0 | 0 | 0 |
| D | — 19 | — 0·01 | 0 | — 0·01 | — 4 | — 0·01 | 0 | — 0·01 |
| E | — 70 | — 0·02 | + 0·01 | — 0·01 | — 10 | — 0·01 | 0 | — 0·01 |
| F | — 100 | — 0·02 | + 0·01 | — 0·01 | — 39 | — 0·01 | 0 | — 0·01 |
| G | — 117 | — 0·01 | + 0·02 | + 0·01 | — 285 | — 0·15 | + 0·04 | — 0·11 |
| H | — 126 | — 0·01 | + 0·02 | + 0·01 | — 443 | — 0·15 | + 0·06 | — 0·09 |
| I | — 121 | — 0·01 | + 0·03 | + 0·02 | — 785 | — 0·43 | + 0·22 | — 0·21 |
| J | — 136 | — 0·01 | + 0·08 | + 0·07 | — 1,499 | — 1·08 | + 0·84 | — 0·24 |
| K | — 128 | 0 | + 0·10 | + 0·10 | — 2,588 | — 1·72 | + 2·09 | + 0·37 |
| L | — 297 | — 0·01 | + 0·30 | + 0·29 | — 3,189 | — 1·41 | + 3·25 | + 1·84 |
| M | — 1,745 | — 0·34 | + 3·22 | + 2·88 | — 3,753 | — 1·75 | + 6·95 | + 5·20 |
| N | — 3,350 | — 0·80 | + 7·82 | + 7·02 | — 4,535 | — 1·49 | + 10·61 | + 9·12 |
| O | — 4,296 | — 1·13 | + 16·43 | + 15·30 | — 4,846 | — 1·49 | + 18·78 | + 17·29 |
| P | — 6,373 | — 1·48 | + 20·96 | + 19·48 | — 6,383 | — 1·50 | + 21·01 | + 19·51 |
| 18 | — 7,838 | .. | .. | + 4·83 | — 8,008 | .. | .. | + 4·93 |
| 17 | — 8,325 | .. | .. | + 5·14 | — 8,550 | .. | .. | + 5·28 |
| 16 | — 8,888 | .. | .. | + 5·49 | — 9,033 | .. | .. | + 5·59 |
| 15 | — 9,671 | .. | .. | + 6·01 | — 9,754 | .. | .. | + 6·07 |
| 14 | —10,281 | .. | .. | + 6·42 | —10,450 | .. | .. | + 6·55 |
| 13 | —10,858 | .. | .. | + 10·66 | —10,958 | .. | .. | + 10·76 |
| 12 | —10,550 | .. | .. | + 6·47 | —10,633 | .. | .. | + 6·52 |
| 10, 11 | .. | .. | .. | + 8·73 | .. | .. | .. | + 8·73 |
| 7 to 9 | .. | .. | .. | + 5·39 | .. | .. | .. | + 5·40 |
| 1 to 6 | .. | .. | .. | + 1·40 | .. | .. | .. | + 1·40 |
| Total . . . . . | | | | + 105·76 | . . . . . | | | + 114·02 |

| Zone. | Average height (ft.). | Topog. (mgals.). | Comp. (mgals.). | Topog. and comp. | Average height (ft.). | Topog. (mgals.). | Comp. (mgals.). | Topog. and comp. |
|---|---|---|---|---|---|---|---|---|
| | Station No. 341. | | | | Dr V. Meinesz's Sea Station. | | | |
| A | + 5 | + 0·10 | 0 | + 0·10 | — 6120 | — 0·21 | 0 | — 0·21 |
| B | + 4 | + 0·02 | 0 | + 0·02 | — 6120 | — 3·86 | 0 | — 3·86 |
| C | — 3 | 0 | 0 | 0 | — 6120 | — 7·70 | + 0·01 | — 7·69 |
| D | — 77 | — 0·16 | 0 | — 0·16 | — 6120 | — 13·75 | + 0·05 | — 13·70 |
| E | — 140 | — 0·23 | + 0·01 | — 0·22 | — 6120 | — 17·47 | + 0·12 | — 17·35 |
| F | — 656 | — 1·43 | + 0·10 | — 1·33 | — 5970 | — 24·56 | + 0·48 | — 24·08 |
| G | — 1485 | — 1·99 | + 0·21 | — 1·78 | — 5970 | — 14·18 | + 0·65 | — 13·53 |
| H | — 2517 | — 2·67 | + 0·34 | — 2·33 | — 5970 | — 9·10 | + 0·72 | — 8·38 |
| I | — 3504 | — 4·91 | + 0·97 | — 3·94 | — 5970 | — 9·98 | + 1·68 | — 8·30 |
| J | — 4715 | — 6·33 | + 2·81 | — 3·52 | — 5970 | — 8·70 | + 2·75 | — 5·95 |
| K | — 4892 | — 3·81 | + 3·93 | + 0·12 | — 5925 | — 5·02 | + 4·75 | — 0·27 |
| L | — 6142 | — 3·18 | + 6·28 | + 3·10 | — 6000 | — 2·90 | + 6·14 | + 3·24 |
| M | — 6408 | — 2·82 | + 11·93 | + 9·11 | — 6100 | — 2·55 | + 11·35 | + 8·80 |
| N | — 6254 | — 1·65 | + 14·68 | + 13·03 | — 6425 | — 1·78 | + 15·09 | + 13·31 |
| O | — 6996 | — 1·97 | + 26·93 | + 24·96 | — 7075 | — 1·99 | + 27·24 | + 25·25 |
| P | — 7804 | — 1·81 | + 25·69 | + 23·88 | — 8425 | — 2·00 | + 27·77 | + 25·77 |
| 18 | — 8200 | .. | .. | + 5·05 | — 8671 | .. | .. | + 5·32 |
| 17 | — 8454 | .. | .. | + 5·21 | — 8783 | .. | .. | + 5·41 |
| 16 | — 8433 | .. | .. | + 5·21 | — 8821 | .. | .. | + 5·45 |
| 15 | — 8120 | .. | .. | + 5·04 | — 8621 | .. | .. | + 5·35 |
| 14 | — 7892 | .. | .. | + 4·92 | — 8458 | .. | .. | + 5·27 |
| 13 | — 7504 | .. | .. | + 7·35 | — 7550 | .. | .. | + 7·68 |
| 12 | .. | .. | .. | + 4·61 | — 7884 | .. | .. | + 4·73 |
| 10, 11 | .. | .. | .. | + 7·85 | — 7696 | .. | .. | + 7·90 |
| 7 to 9 | .. | .. | .. | + 4·90 | .. | .. | .. | + 5·00 |
| 1 to 6 | .. | .. | .. | + 1·43 | .. | .. | .. | + 1·42 |
| Total . . . . . | | | | + 112·61 | . . . . . | | | + 26·58 |

# APPENDIX III

An expedition, sent out by the Royal Society in 1896, made a boring in the coral island of Funafuti in the Pacific Ocean, to a depth of 1114 ft. The cores obtained from this boring are at the British Museum (Natural History), and appeared to be the only available source from which to form an estimate of the mean density of the coral formations in coral islands.

Mr. M. H. Hey kindly undertook to determine the densities of the cores. His remarks are given below. Commenting on these results, Prof. J. Stanley Gardiner writes as follows :

" The pieces taken are such as to give too high figures for each individual one if I read them aright. I think you would be absolutely safe to take 1·8, but of course you could go to extreme 2·0. I got a lot of similar determinations from coral island rocks made for me once and they were below 1·8".

Extract from letter from Mr. M. H. Hey, dated June 14th, 1934, Mineral Department, British Museum (Nat. Hist.).

" It is rather unfortunate that the quantity required should be the bulk densities as saturated with water. This cannot readily be accurately determined. I have proceeded as follows : 22 cores were selected from representative depths, weighed, measured carefully with the millimetre scale, and the volume calculated. The mean dry density* was so obtained, and from this and the known dolomite content the mean wet density† was calculated.

" The determinations were performed by Mr. S. E. Ellis of this Department under my direction. The probable accuracy of the data cannot exceed 0·05 and may not exceed 0·2. I should add that I am afraid the value of the results will be considerably reduced by the fact that a large percentage‡ of the cores are not solid, but consist of broken fragments. It would obviously be impossible to find the mean wet density of these disintegrating cores in their original state and I have not examined any of them. It is certain, however, that these cores which disintegrated must have been much more porous than those which did not, and would, therefore, have a considerably lower mean wet density. I should estimate the mean wet density of these cores which disintegrated at from 1·5 to 2·0, probably mostly between 1·8 and 2·0 ".

* *I. e.*, the mean density of the dry core as a whole, including the pores.
† *I. e.*, the mean density of the core with all the pores filled with water.
‡ Perhaps 30–50 %; I have not counted them.

| Number of core. | Approximate depth in feet. | Mean dry density in grammes per c.c. | Mean wet density in grammes per c.c. |
|---|---|---|---|
| 3 | 3 | 2·02 | 2·28 |
| 15 | 15 | 2·52 | 2·60 |
| 55 | 64 | 2·24 | 2·42 |
| 94 | 82 | 2·26 | 2·43 |
| 141 | 160 | 2·33 | 2·47 |
| 175 | 200 | 1·96 | 2·24 |
| All cores between 200 and 380 ft. disintegrated. | | | |
| 205 | 380 | 2·40 | 2·52 |
| 216 | 435 | 2·44 | 2·54 |
| 229 | 452 | 2·62 | 2·66 |
| 258 | 512 | 2·28 | 2·44 |
| 294 | 552 | 2·14 | 2·35 |
| 304 | 598 | 1·68 | 2·06 |
| 335 | 652 | 2·01 | 2·28 |
| 363 | 695 | 1·57 | 2·00 |
| 41a | 760 | 2·72 | 2·74 |
| 163a | 810 | 2·47 | 2·58 |
| 254a | 855 | 2·60 | 2·66 |
| 339a | 898 | 2·50 | 2·60 |
| 431a | 950 | 2·24 | 2·46 |
| 520a | 1000 | 2·43 | 2·67 |
| 603a | 1050 | 2·64 | 2·69 |
| 701a | 1110 | 2·68 | 2·71 |

## DESCRIPTION OF PLATE I.

FIG. 1.—Seaward profile of Atolls, Maldive Archipelago.

FIG. 2.—Gravity Anomalies, Minikoi and Maldive Sections.

## Seaward Profile of Atolls
## Maldive Archipelago

Vertical scale twice Horizontal scale

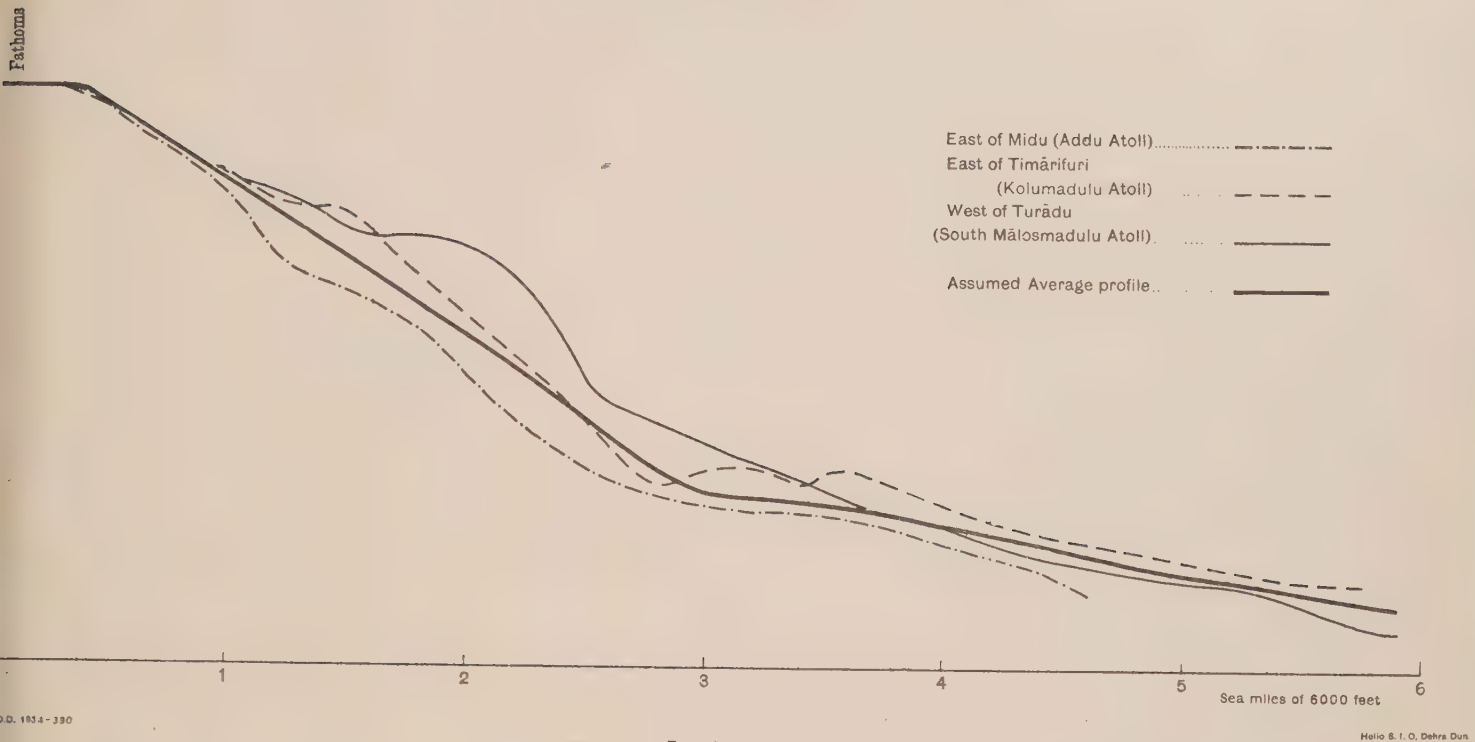
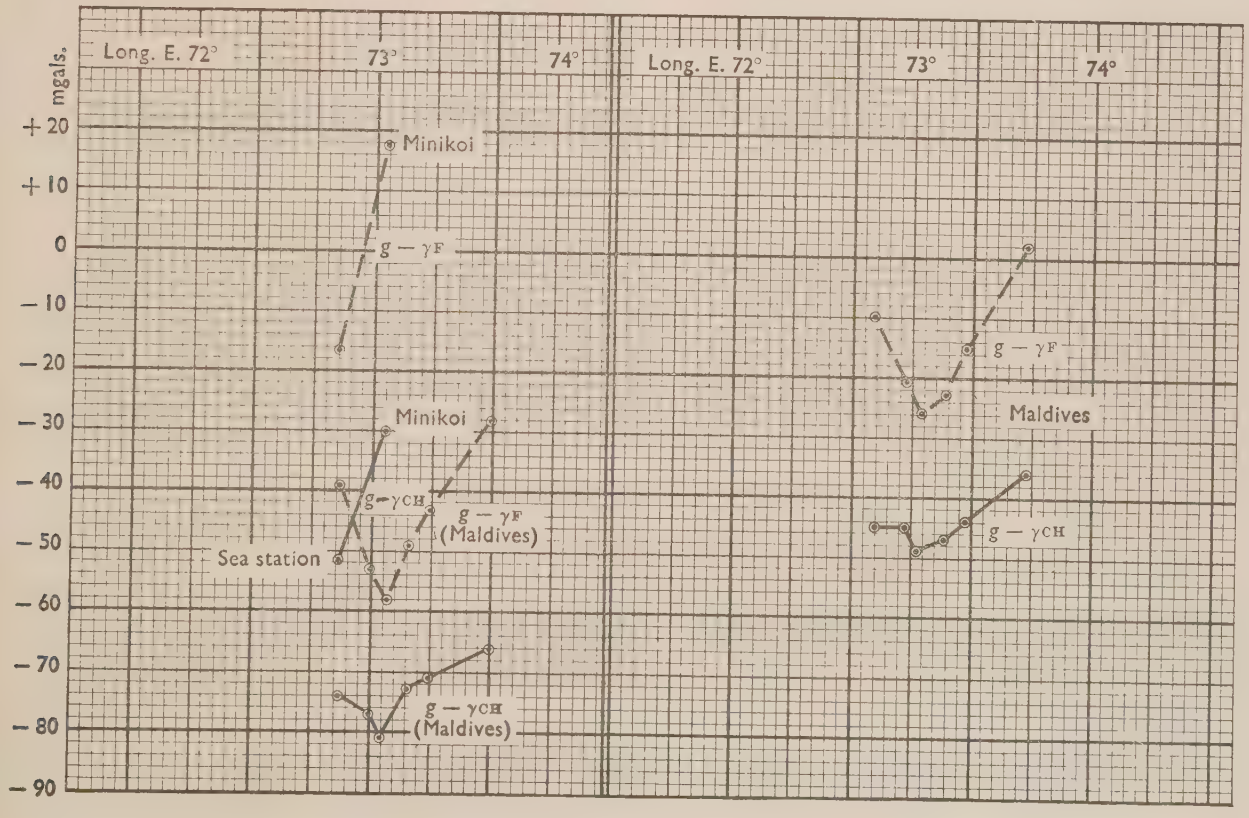



Fig. 1.

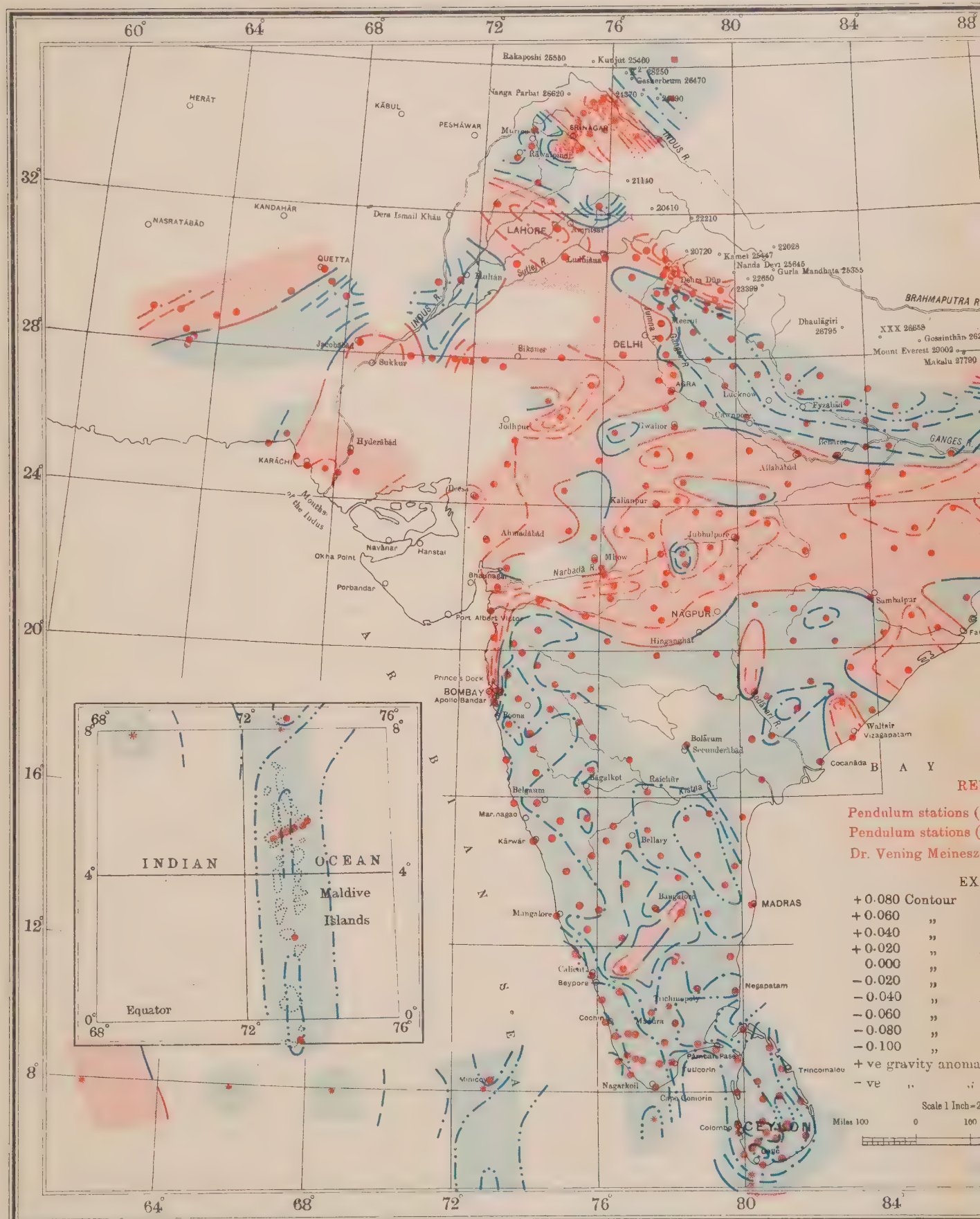



A
Gravity Anomalies
Minikoi and Maldive
Sections
assuming normal rock density (2·67).

Fig. 2.

B
Gravity Anomalies
Maldive Section
assuming 3000 feet coral (1·8)
and normal density below.

[*Adlard & Son, Ltd. Impr.*

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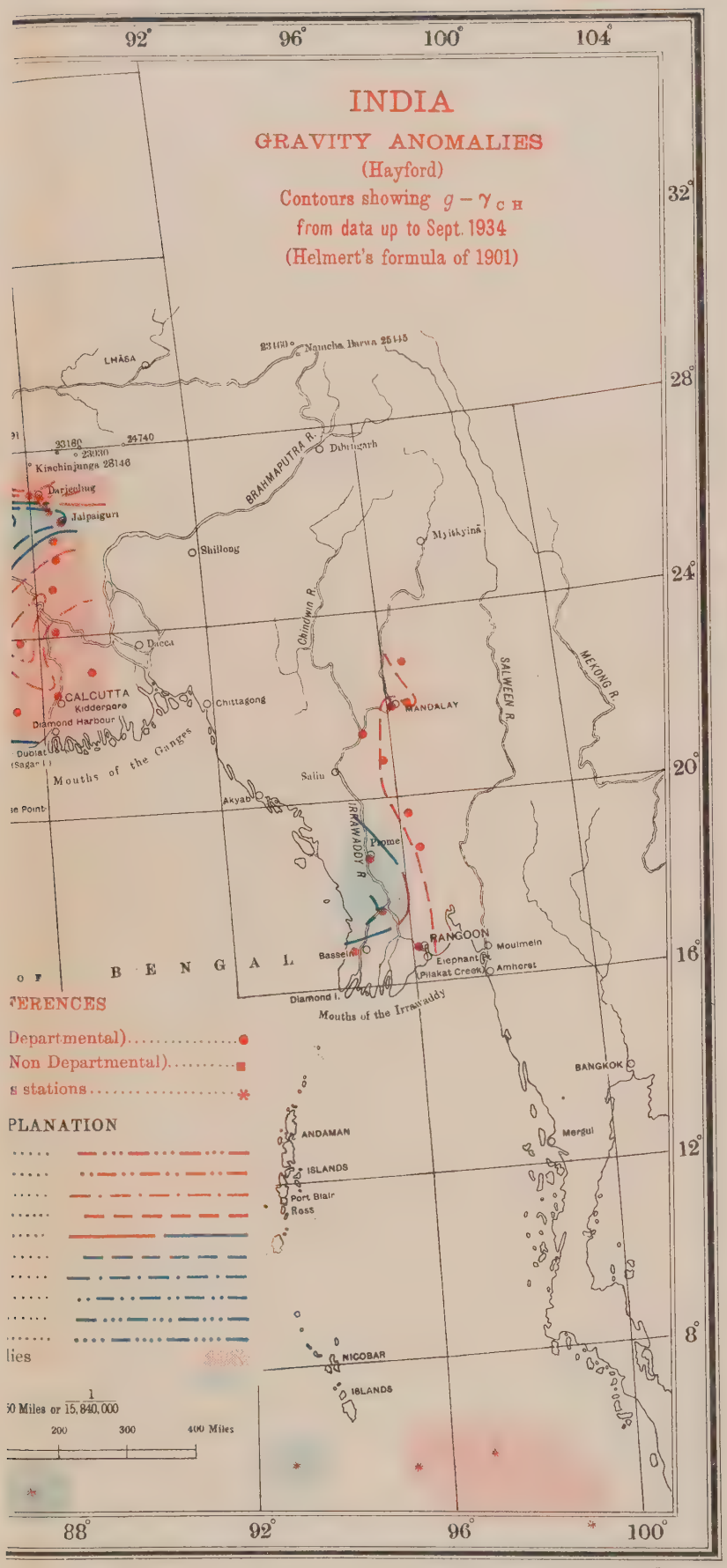
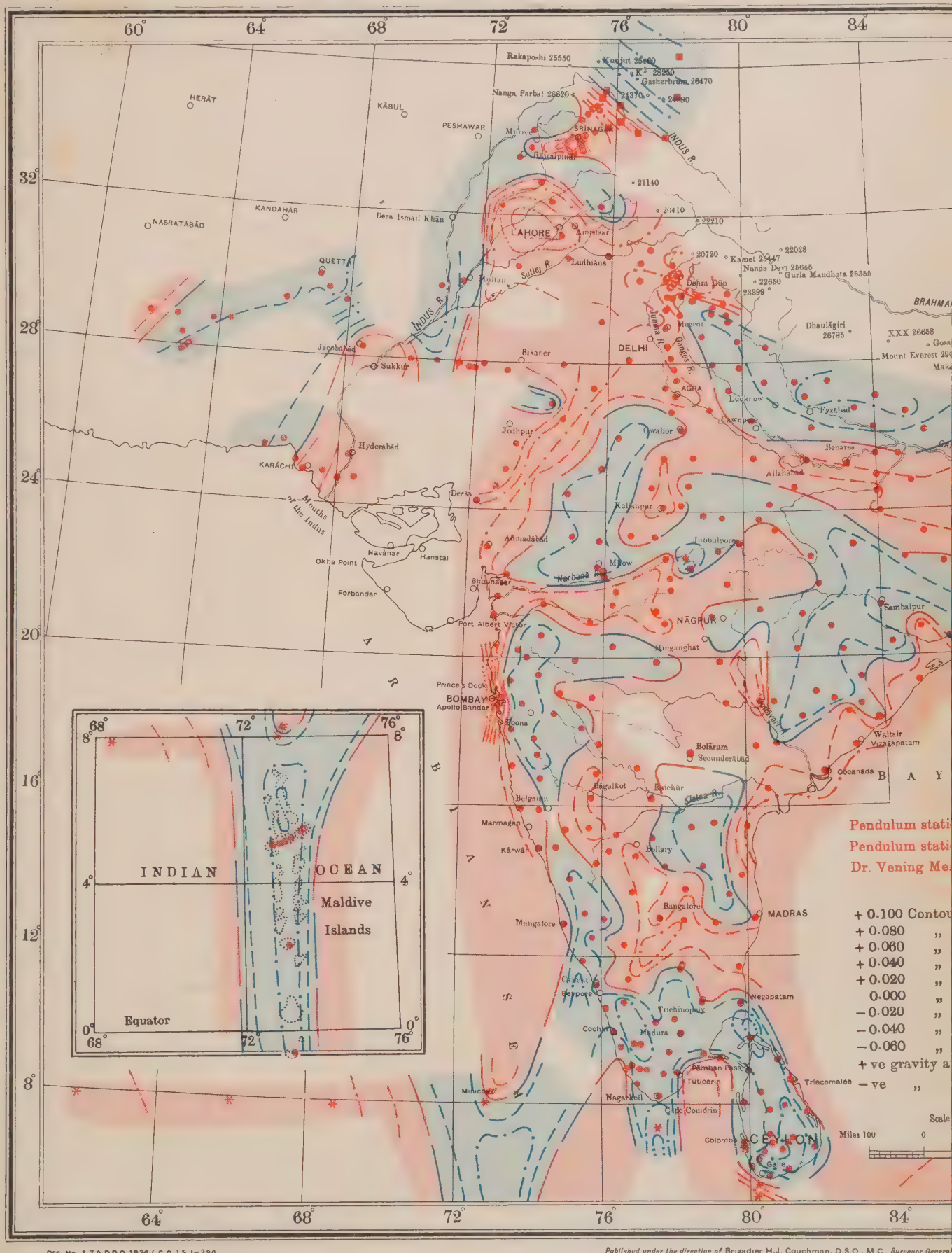
1934




HELIO. S. I. O. DEHRA DÜN.

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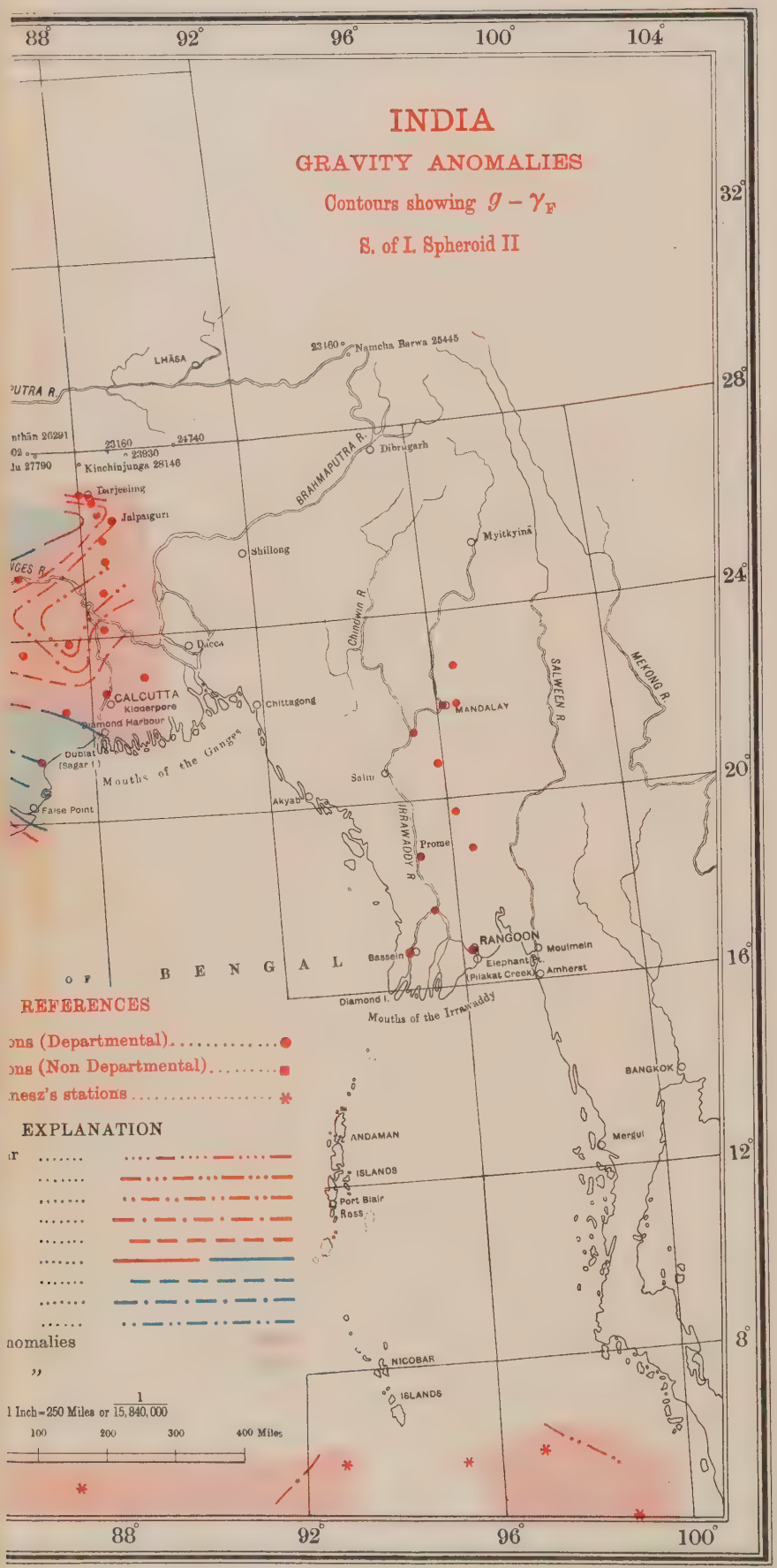
1934

Chart II

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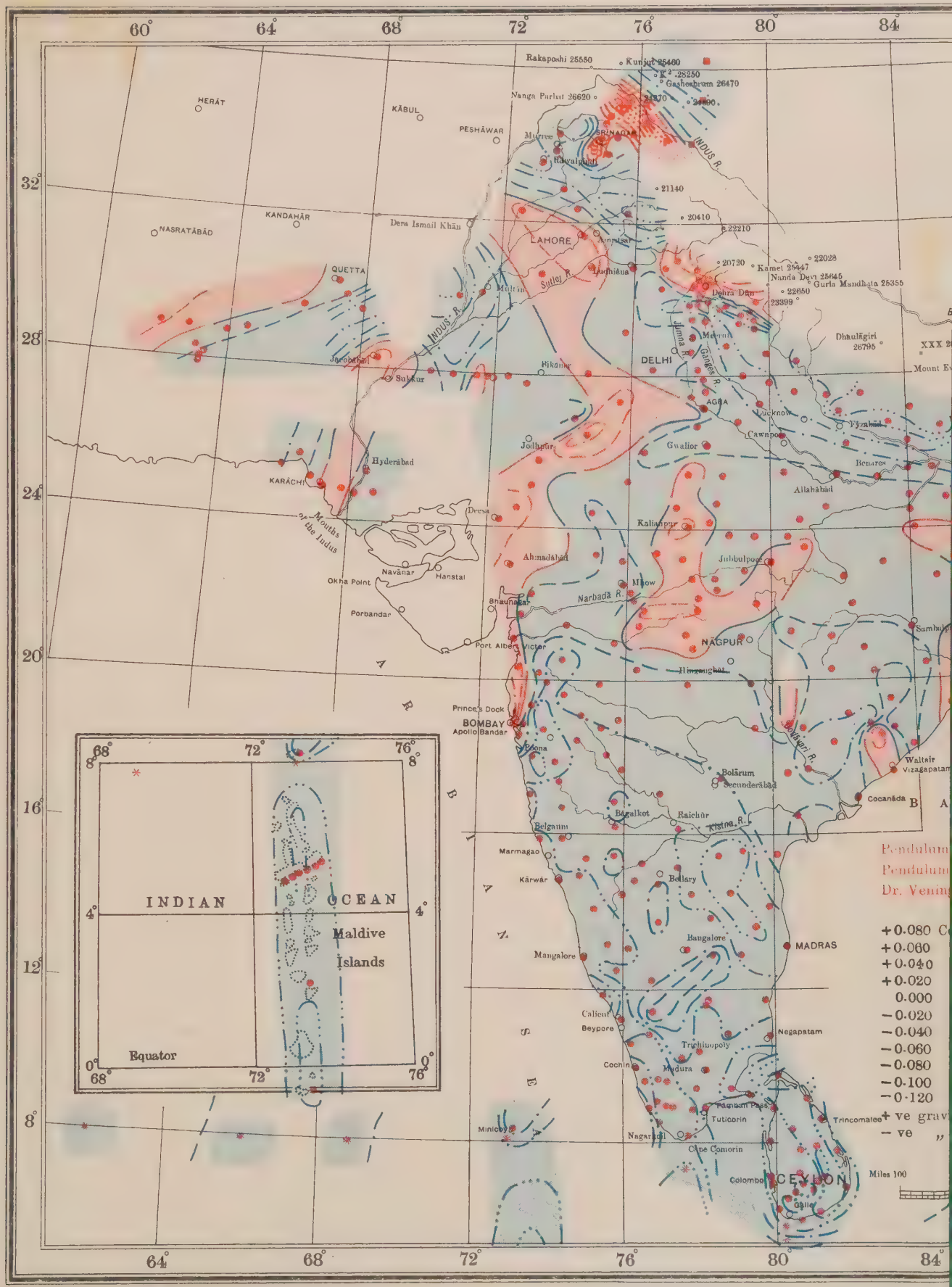


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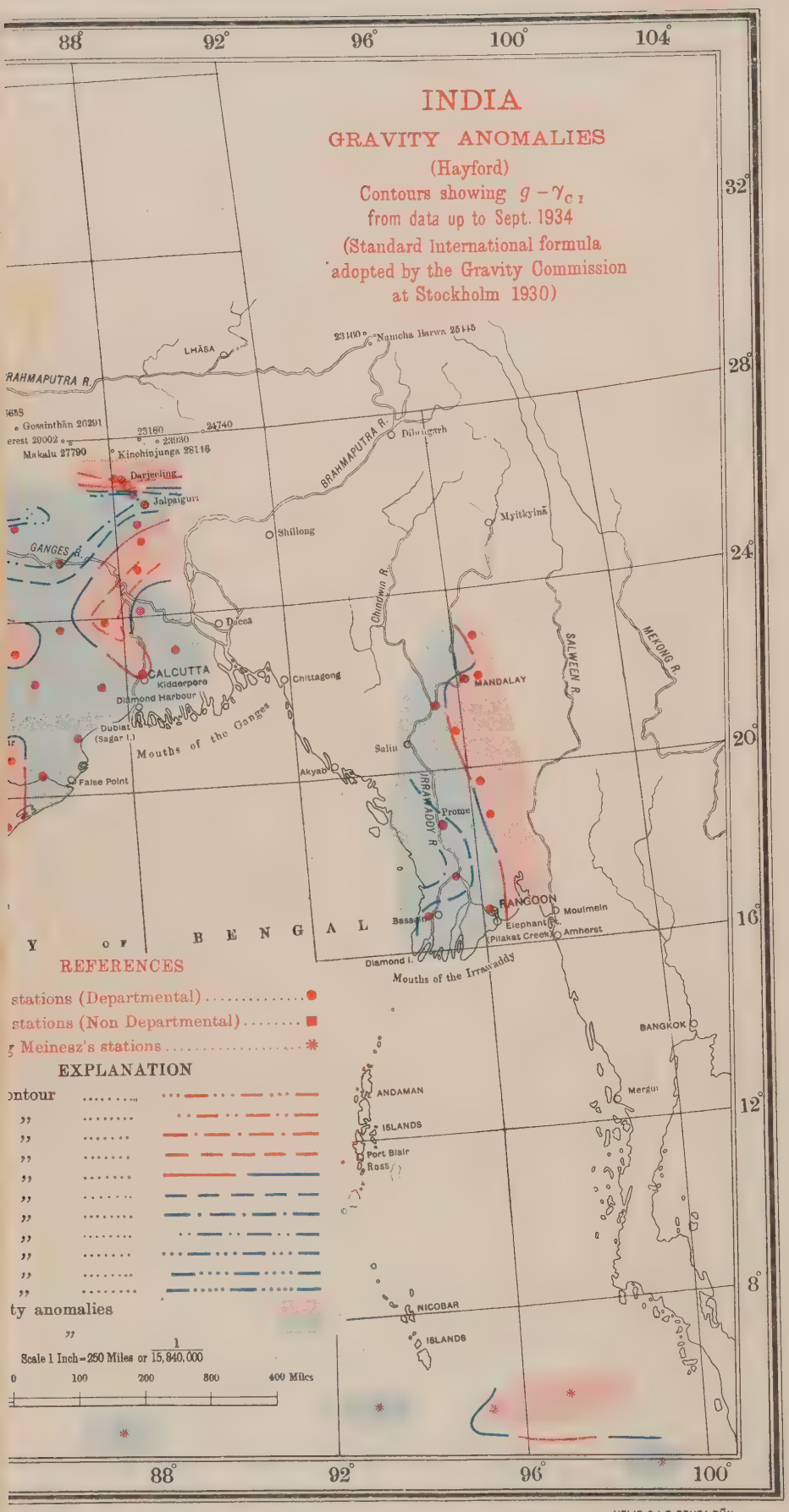
1934

Chart III

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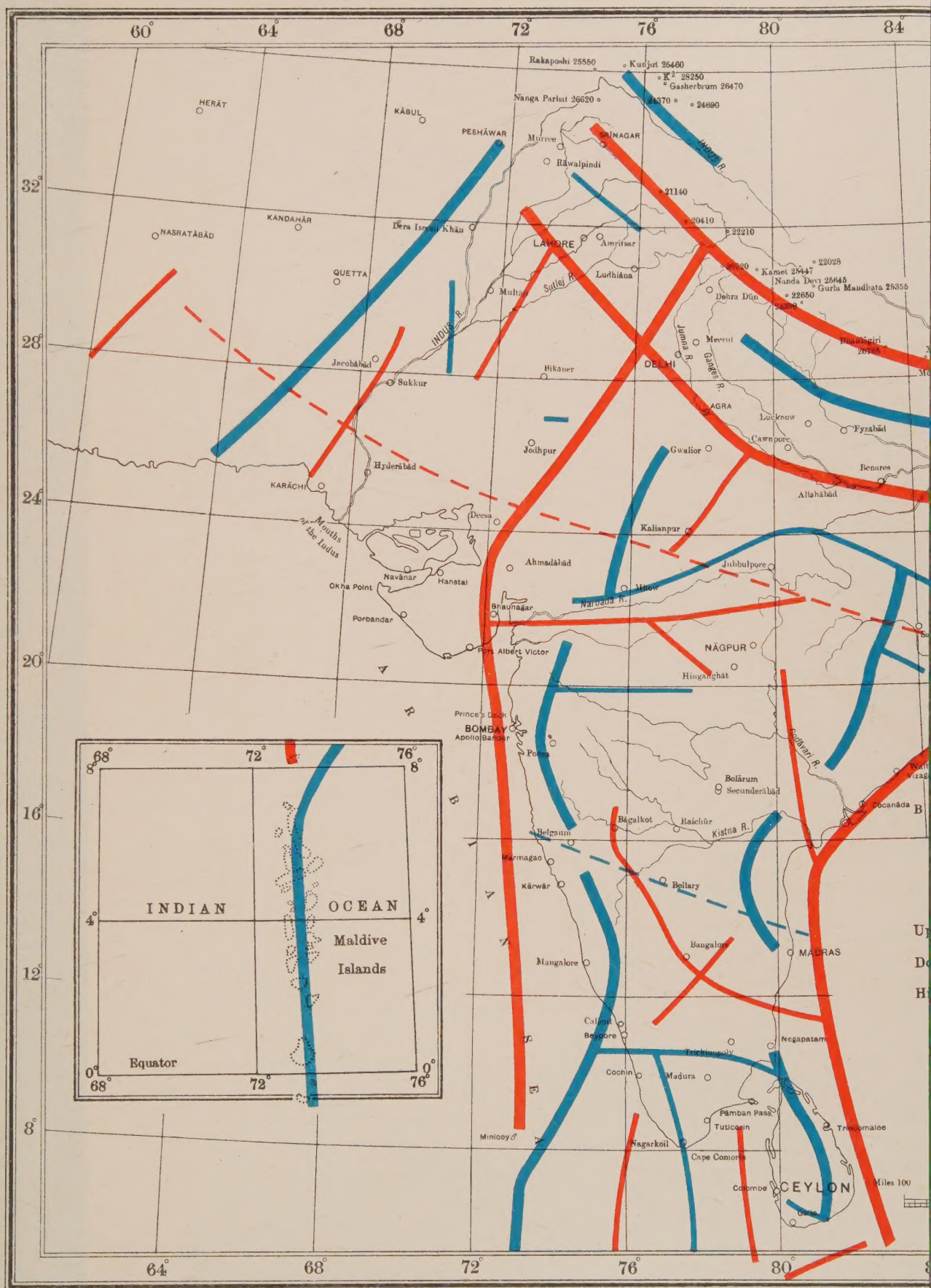


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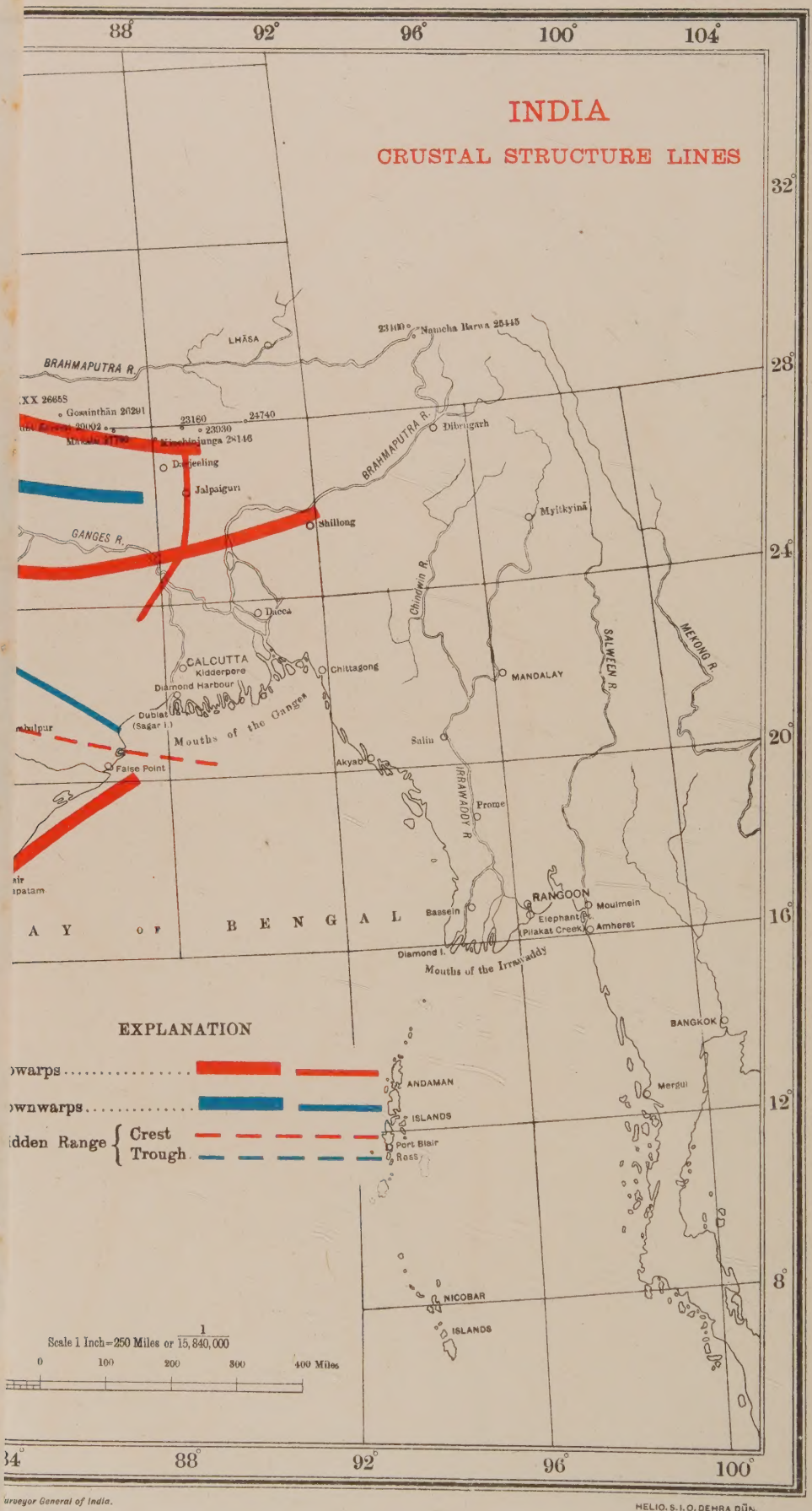
Chart IV

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